Integrated Lightweight Optical Systems

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Introduction:

Fielding an ultra lightweight optical system such as NGST requires a new approach to space optics. The requirement of one to two orders of magnitude increase in aperture size, implies an equivalent decrease in areal mass, ultimately to less than 1 Kg per square meter, just to be able to launch a system at an affordable cost. Thus innovative ways must be sought to deploy lightweight optics. It is the point of this paper to emphasize the need for total systems integration on the development path of this system, and to point out some critical needs, which are being addressed by some of Lockheed Martin's existing programs.

Problem:

Large apertures and light weight implies directly low stiffness structure, with low inertia and very low resonance frequencies. Thus optical figure and wavefront control can only be achieved by some kind of active mirror actuator system. The question of which elements must be active, primary mirror or secondary elements or both is still unanswered awaiting completion of concept studies and system performance trades. Lockheed Martin is primarily a systems engineering and integration business, thus the question of actuator and systems controls and their integration to the as yet undefined optical system is of prime concern. A specific feature of this problem is the clear need to involve systems integration in parallel with the optical mirror configuration development.

Approach:

The optics train will involve both cryogenic actuators and real time control systems on one or more optical elements. Thus a total system approach is needed, where total platform areal density metrics include not only the mirror and support structure, but also actuators, wiring, power supplies and amplifiers, multiplexing electronics, sensors and control system hardware and software. In this discussion we are restricting are arguments to the technology of mirror actuators and associated electronics.

Technology Maturity:

We have available to us miniaturized low power electronics for driving actuators. We have control algorithms and DSP's that are fast enough (with more chip integration coming down the line). We have lightweight supporting structure concepts and design tools, and we have low cost deformable mirror technology (which is perhaps not light enough yet). What we **do not have** yet are proven cryogenic actuators. We have many concepts and are actively working in three maor directions. The first is single crystal piezoelectric materials, the second is magnetostrictors, and the third is precision electric mechanisms. The big difficulty in pursuing these alternative concepts is that their implementation depends on optical configuration. For example, it is unclear whether the optical elements will be thin lightweight glass shells, coated composites, or micron thickness flexible membranes. In addition, decisions have not been made on whether figure and wavefront control should be combined or not, and what is the split on these corrections between primary and secondary optical elements. Clearly much more "out of the box" thinking is required to innovative integrate and package the system to meet the areal density goals.

Lockheed Martin Background in Smart Materials Systems:

LM has have many Smart Materials Programs focused on proof of concept, however a few are heading into real world implementation and we can see relevance in the lessons learned from these programs. The lessons learned are 1) systems integration, and parallel technology development are the best cost effective approach and 2) iterative demonstrations enable timely injection and evaluation of new products that help optimization, fix screw-ups and reduce final product risk both performance and cost. In particular, the prediction of total performance from individual component performance tests is a flawed approach with a proven track record. The example shown is our successful DARPA Composite Smart Materials program. We used two iterations on a complete system that operated autonomously as a smart skin for sonar "ping" cancellation on underwater vehicles. A third iteration concerned miniaturization and cost reduction.

Active Systems Component Technology:

Mirror figure control and beam quality optimization is achieved by a combination of actuators and electronic controls. Our experience is that the actuator drive amplifiers and associated controls are a significant part of the system in terms of weight and power requirements. While the bandwidth for these large earth outlooking mirrors is low, inward looking optical observations require compensation at much larger bandwidths, typically of the order of 1KHz. The control system must be adaptive, autonomous, and capable of structural self identification. LM has been developing integrated control systems with exactly these features. Almost universally we have adopted feed forward control systems with local sensor actuator pairs driven by dedicated Digital Signal Processors. Current emphasis has been on amplifier/power supply minimization as external commercial interests are driving the DSP processor size and weight down while simultaneously increasing performance. The demands from the active controls community for this capability will certainly produce custom ASIC chips in the next few years with much lower costs and weight.

Distributed Actuator Technology

The successful light weight deployable optical structure will have two primary features, a lightweight distributed actuator system and an affordable cost. A secondary feature is reliability, either the actuation system will not fail or the system can adapt to and recover from, an isolated unit failure. We have developed an integrated approach to actuator arrays that exploits 1) commercial high reliability chiplet capacitor fabrication techniques, and 2) microelectronic fabrication techniques. Printed circuits can be routinely fabricated on 5 mil fiberglass circuit boards, Kapton films and even ceramic sheets and films. We have exploited these together with pick and place assembly to produce low cost actuator arrays. For the large mirror application, the challenge is to scale these techniques from tens of centimeters to tens of meters. In all probability the solution will be a highly local modular approach with global interconnectivity.

Materials Development:

The Advanced Technology Center has a long heritage of solid state actuators, with emphasis on electrostrictors (PMN), with extensive patent protection of the formulations. We have capability to fabricate raw materials into devices and systems that typically consist of glued stacks and co-fired multilayers. We have experience also with other actuation systems including shape memory alloys and magnetostrictors which we are targeting, in particular, for cryogenic actuators for high bandwidth applications.

Internal Research and Development:

Lockheed Martin has focused on the actuator and beam control systems largely in support of technology demands from the AirBorne Laser and Space Based Laser programs. It is the latter program that is driving our interest in cryogenic actuators. It is clear that this technology of cryogenic beam control can be directly leveraged for NGST and other large lightweight mirror systems. Thus we are targeting integration of low power actuators with power supplies and control systems of one hundredth of current systems size and weight. The path to these goals requires low voltage, less than 30 volts for all systems and we have demonstrated this using a deformable mirror as the system exemplar.

Summary:

The message of this paper is that the successful development of an ultra lightweight mirror system with areal density in the 1-2 Kgms/sq. meter will only happen if a broad based systems approach to development is applied. This implies complete integration of materials, shape control actuators and electronic systems. It is also implicit that knowledge gained from flight experience with light weight structures and cryogenic systems must be incorporated. Thus every opportunity to get something up, no matter how simple, should be seized, and the resulting data disseminated to all players as quickly as possible. We all want to see results within our work lifetimes.